Satterthwaite (T. E.)

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NOTES AND PRACTICAL STUDIES

ON THE

MINUTE ELEMENTS OF THE NERVOUS SYSTEM.

BY

Dr. THOMAS E. SATTERTHWAITE.

[*REPRINTED FROM THE NEW YORK MEDICAL JOURNAL, SEPT.*, 1878.]

NEW YORK:
D. APPLETON & COMPANY,
549 & 551 BROADWAY.
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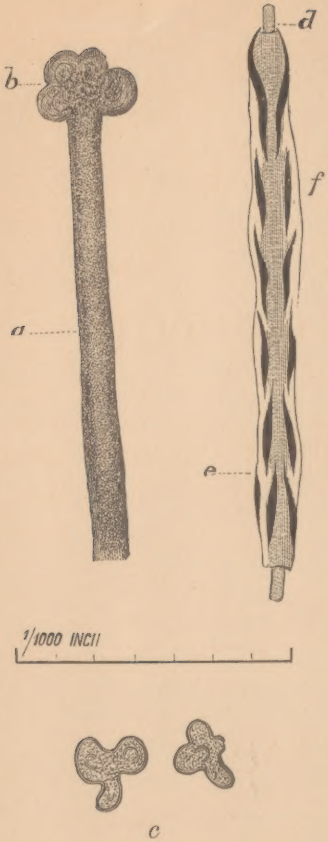
FIG. 1.



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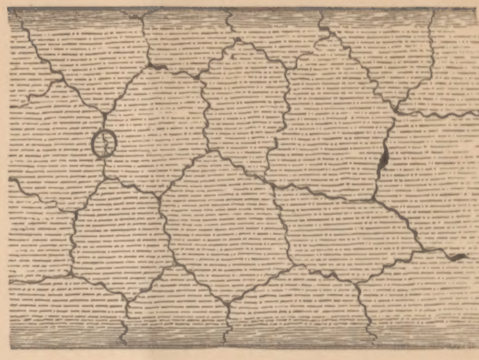

FIG. 5.

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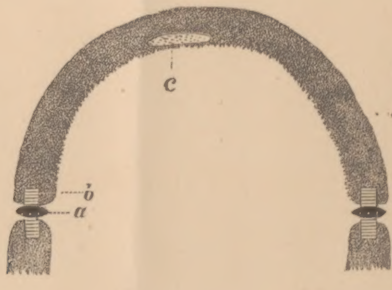

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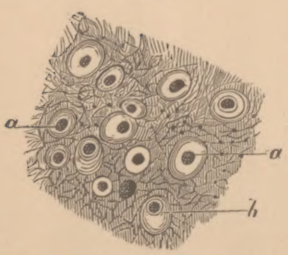

FIG. 1.—*a*, Myelinic fibre in a state of "coagulation;" *b*, myeline exuding from the broken end of the fibre; *c*, drops of myeline separated from the nerve fibre; *d*, axis cylinder; *e*, nucleus of Henle's sheath; *f*, arrow markings.

FIG. 2.—FUNICULUS OR NERVE BUNDLE COVERED WITH ENDOTHELIUM (EPITHELIUM). From the sciatic of the frog.—Hartnack, object. 4, oc. 2.

FIG. 3.—*a*, Ranvier's disk; *b*, Frommann's lines; *c*, nucleus of interannular segment.

FIG. 4.—CROSS SECTION OF THE HUMAN CORD JUST BELOW THE DECUSSATION. *a*, Axis cylinder; *b*, sheath of Mauthner.

FIG. 5.—HUMAN MYELINIC NERVE. *a*, Interannular segment; *b*, Ranvier's node, *c*, nucleus of the interannular segment surrounded by granular protoplasm; *d*, Henle's sheath with nucleus.

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A GREAT deal of extended work has been done of late years on the minute structure of nervous tissue; but still there seems to be a general agreement among recent writers on these matters that we have by no means reached a clear understanding of the histological characters of even the simpler elements.

As examples, we may cite the conflicting views that are expressed as to the composition of the axis-cylinder in medullated nerves; as to whether the pale or gray fibres branch or do not; as to the processes of ganglion corpuscles, and their relation to other similar corpuscles and nerve-fibres; as to the presence of spiral fibres in the human species; the methods by which nerves terminate, etc. It will be my aim in this paper to classify our existing knowledge on the principal fundamental points, and add the result of my own experience so far as it bears upon them.[1]

In getting a conception of the minute anatomy of the nervous system, we must think of it as composed of three principal parts, of fibres (1) connected on the one hand at the nerve-

[1] Thanks are due to Dr. W. H. Porter, Curator of the Presbyterian Hospital, and to my students Messrs. Aycrigg and Carryl, for their assistance in the preparation of many of the microscopical specimens.

centres with certain elements, the *ganglion corpuscles* (2), and at the periphery with others that have been named *terminal bodies* (3). The nerve-centres are the brain, cerebro-spinal axis, and certain other smaller centres known as spinal or sympathetic ganglia, according as they are in connection with the cerebro-spinal or sympathetic system of nerves.

At the points where the nerves are finally distributed, they enter the bodies known as terminal, which are called, according to certain peculiarities in them, Pacinian bodies, tactile corpuscles, end bulbs, etc. So far as we know, however, they may not always end in this way, but may form terminal networks, or indeed end in epithelial bodies, as in the retina, or even possibly may have free termini. It is convenient to study these different parts in the order in which they have been named.

Nerve Fibres.—Of these there are three kinds that have distinctive differences: 1. The myelinic or medullated fibres; 2. The fibres of Remak; 3. Ultimate fibrils. Intermediate forms, such as have been described by various writers, under the names of protoplasmic processes, primitive fasciculi or naked axis cylinders,[1] varicose cylinders, etc., will be noticed in other connections.

Myelinic Fibres.—These are also known as the medullated. To the naked eye they appear white and glistening and are the main constituents of the peripheric nerves, though they occur in less number in the sympathetic and also in the brain and cord. Three distinct parts constitute each fibre: (*a*) a central cylindrical cord, the axis-cylinder about which is a (*b*) coating of a soft homogeneous fatty substance, called myeline (medulla, white substance of Schwann), forming for the axis-cylinder a sort of tubular sheath, while exterior to both is a delicate membrane or envelope (*c*), the sheath of Schwann or primitive sheath.[2] These fibres run a parallel unbranching course, except near their termini or origin, and are surrounded by a

[1] Max Schultze, "Manual of Histology," p. 117.

[2] A most unfortunate source of confusion among histologists has arisen from the use of the word neurilemma, which by some is spoken of as synonymous with Schwann's sheath (Frey), and by others as the connective tissue which binds the nerve fibres together (Klein, Rutherford). We shall avoid the term altogether.

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connective-tissue coating of varying thickness. Their diameter varies according to their situation and the degree of their tension or relaxation. In the nerve trunks the average diameter lies between $\frac{1}{70}$ and $\frac{1}{150}$ millimetre. In the brain they are described as having sometimes a diameter of $\frac{1}{500}$ millimetre, but it is difficult to determine the question of a medulla in such small fibres.

To study the properties of a myelinic nerve in as nearly the fresh state as possible, we may take the sciatic from a frog that has just been killed. Having removed it with care and placed it in a drop of water on a slide, we may separate the fibres carefully with needles, taking care not to tease them. Having adjusted a covering glass, we shall see that from the broken end of the nerve a soft substance is exuding (Fig. 1, *b*); in a few minutes this matter is pushed off in the form of drops of irregular shapes (Fig. 1, *c*). This material is the myeline or medulla. It will be seen to refract the light strongly, and show concentric markings. It will also be seen that each fibre has a double contour and is divided at tolerably regular intervals by transverse lines, which are now known as Ranvier's nodes. (*See* Fig. 5.) Midway between each node we may perhaps see an oval body surrounded by a broad expansion of protoplasm. In a few fibres we may see that a fine thread-like process is projecting from the broken ends of the nerve fibre—the axis-cylinder (Fig. 1, *d*), while the whole fibre is enclosed by a delicate tightly-investing membrane, the sheath of Schwann. Possibly we may also see the oblique or arrow markings (incisures of Schmidt) (Fig. 1, *f*), which seem first to have been accurately described by Schmidt,[1] of New Orleans, later by Lantermann, of Cleveland,[2] Shaw,[3] and others.[4] Much the same appearances can be obtained by the use of iodized serum.

[1] On the construction of the dark or double-bordered nerve fibre, *Monthly Microscopical Journal*, May 1, 1874.

[2] Ueber den feineren Bau d. markhält. Nervenfasern, *Archiv für mikroskopische Anatomie*, 1870, vol. xiii., p. 1.

[3] Some peculiarities in the myelinic peripheral nerves, etc., *Journal of Nervous and Mental Diseases*, January, 1876.

[4] They had been noticed by Remak as early as 1837, and subsequently by Stilling and Lockhart Clarke.

The double contour is not always to be seen in all the myelinic nerves, but is most marked where they show varicose swellings, due to a preponderance of myeline at the enlarged point. From this fact and another, that the drops of myeline when separated from the fibre show the same double contour, it is argued that the double marking in the fibre is due to a refracting (double) of the myeline, and has nothing to do with the membranous sheath. These varicosities just mentioned are not to be confounded with the bulgings of the ultimate fibrils, or with the "necklace" appearances seen in the course of the fibres of Remak, both of which latter may probably be regarded as artificial productions, either from stretching in the act of teasing or from the imbibition of water. In the brain of the calf they are frequently seen, and they are said to be found in the int~~er~~cranial part of the olfactory, optic, and acoustic nerves. The fibres in which this change occurs are usually quite small.

Staining in Picro-Carmine.—This reagent has been recommended by Ranvier. It is satisfactorily prepared by Rutherford's process.[1]

Taking precautions not to injure the nerve in removing it, mount in the solution. The nuclei will then be stained a brick-red, while the sheath of Schwann, and, in fact, the whole nerve, will be stained yellow. It is said that, if the axis-cylinder projects, it will be stained a bright red, though twenty-four hours may be required to effect the staining. In my hands picro-carmine has not proved so successful a coloring agent as some others.

Staining with the Nitrate of Silver.—The sciatic or any peripheral nerve may be employed. Expose it without removal in a frog that has just been killed. Then dry up all

[1] He takes 100 C. C. of a saturated solution of picric acid. He then prepares an ammoniacal solution of carmine by dissolving one gramme in a few C. C. of water, with the aid of an excess of ammonia and heat. He then boils the picric acid solution on a sand bath, and when boiling adds the carmine solution. He then evaporates the mixture to dryness, then dissolves the residue in 100 C. C. of water, and filters. If the solution is not clear, he adds more ammonia, evaporates, and then dissolves as before.

fluid from about it, and pour on a solution of the nitrate (1 to 1000). In this way the nerve-fibres will be made rigid. They are then to be removed with a pair of delicate scissors, and placed in a flat vessel containing more of the solution. After a few minutes the nerve will look turbid, and then it should be cut out and washed in distilled water, and exposed to the sunlight. In a variable time (10 to 15 minutes) the turbid appearance will give way to a brown coloration. Examining a single funiculus or bundle in glycerine, it will be seen that it has an epithelial (endothelial) coating of one or more layers.

If another funiculus be separated with fine needles,[1] the same care being taken to spread the fibres apart and not tease, and so lacerate them, it will be seen that each fibre contains a series of *Latin crosses* at certain pretty regular intervals. The transverse bar of the cross corresponds to the "annular constriction" seen at Ranvier's node, while the axis-cylinder forms the longitudinal bar. Close observation with high powers will show that this latter is marked by transverse lines of a dark brown or black (Frommann's lines). It appears probable, as Ranvier[2] explains, that, owing to the break in the myeline at the "annular constriction," the particles of silver gain an entrance to the axis-cylinder at this the only unprotected spot. If the action of the salt is long continued, the axis-cylinder is colored for a somewhat longer distance. The transverse bar seems to be formed of two conical segments set base to base. The position of this biconical segment usually corresponds in position with the "annular constriction," but it would appear that they may be separated, for, when the tissue of the nerve has been put upon the stretch, the biconical segment may be drawn away from the annular constriction. (*See* Fig. 3.)

Now, as Schwann's sheath is understood to end at the annular constriction, where it is cemented to the next adjoining segment just as epithelial cells are joined together, the biconical disk may belong to the axis-cylinder exclusively, and

[1] Milliners' are the best.

[2] "Leçons sur l'Histologie du Système Nerveux," Paris, 1878.

merely constitute a dividing line between its segments. According to Engelmann, the axis-cylinder is divided up into portions corresponding with the interannular segments.

Staining of the Nerve in Osmic Acid—Semi-Desiccation.—Osmic acid is one of the most valuable reagents for histological work, and the method now to be described (a modification of Ranvier's[1]) succeeds well. Take the sciatic of the frog, or any other peripheral nerve, carefully remove a portion with the surrounding tissue, keep the whole extended upon a flat bit of cork with pins, and then dip it into a vessel containing a one per cent. watery solution of osmic acid.[2] The vessel is then to be exposed to the light. The whole nerve will be more or less thoroughly stained in a few hours. The external portions, however, will be stained in a few minutes, and they may be removed by careful separation with fine needles. To mount, take a glass slide and slip it under the nerve-fibres, while the needle is employed to draw them up on to a dry part of the slide where they can be placed side by side. Then remove the excess of water with bibulous paper, and let the fibres get so dry that they adhere to the slide. Place about them a ring of tissue-paper so that when the cover is adjusted it will not press upon the fibres. Fix the cover at different points with paraffine, then put a drop of glycerine upon one side, and a drop of water upon the other. The union of water and glycerine should be allowed to go on for twenty-four hours in a damp place. The constrictions and arrow-markings are usually well seen. The nuclei also are occasionally to be found in a niche of the myeline. These bodies, however, are better seen in specimens that have been a short time (15 or 20 minutes) in osmic acid, and then in picro-carmine a few hours. It still is a question among histologists whether the arrow-markings are artificial or not; each of the sections lying between the markings is called the cylindro-conical segment (*Hohlcylinder*, Kuhnt). (*See* Fig. 1.)

Transverse Sections of Myelinic Nerves.—Certain points are best seen by making transverse sections. Prepare the sciatic

[1] *Op. cit.*

[2] The solution should, of course, have been kept in a dark bottle away from the light.

of a frog or any of the human peripheral nerves by immersing a few days in a sherry-colored solution of bichromate of potash or in Mueller's fluid,[1] and then in ninety per cent. alcohol, until the tissue is hard enough to cut. Then it is to be mounted in the microtome in wax and oil of about its own consistence. Sections are to be made with the razor, or it may be mounted in elder-pith in the following way: Bore out from the centre of the pith-cylinder a cylindrical hole a little larger than the trunk of the nerve, then immerse the whole in water, and the pith will begin to swell. As soon as it has firmly embraced the nerve, sections may be made with the knife. Ammonia-carmine will stain the axis-cylinder well, but the outline of the cut will appear irregular rather than round. This appearance is doubtless artificial. In my hands, borax carmine[2] has proved much better than the ammonia-carmine, as it diffuses very little, and much of the excess may be removed by dilute acetic acid (about one-quarter per cent.), in which the specimen should remain, from a few seconds to a minute or two, until it has become bright to the eye. The further steps in the process of making a permanent preparation are the same as those for other specimens; i. e., it may be mounted in glycerine and water, or clarified by clove oil and mounted in dammar varnish or Canada balsam.

Preparation by the Bichromate of Ammonia.—Ranvier employs of this a two per cent. solution, allowing the specimen to remain, with frequent changes of the fluid, from two or three months to a year. The sections are to be stained in ammonia-carmine or picro-carmine, and mounted in glycerine. It will then be seen that immediately about the axis-cylinder is a sheath. This is called by Ranvier the sheath of Mauthner, from the author who described them. (*See* Fig. 4.) Specimens prepared in the ordinary way, by long immersion in

[1] The well-known eye-fluid, of which the composition is—

Bichromate of Potash,	2–2½	grammes.
Sulphate of Soda,	1	"
Distilled Water,	100	"

[2] The powder is prepared by Eimer & Amend of this city (205 and 207 Third Avenue) according to Arnold's formula. The strength required is gr. xv to ℥ i distilled water.

Muller's fluid alone, or subsequently in the chromic acid solution (gr. ij– ℥ i) and stained with ammonia-carmine, occasionally show the same thing.

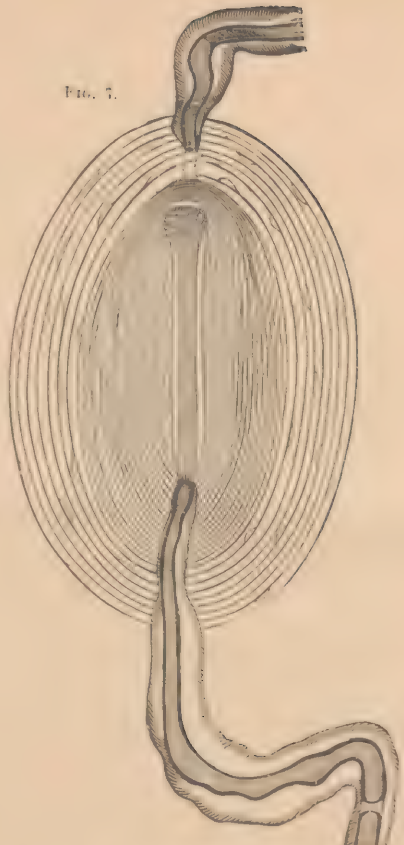
Sometimes histologists find that embedding in gum succeeds best in securing these transverse sections of nerves. The difficulty of the task is one of considerable moment. The method is as follows: Take a fresh nerve, harden it in osmic acid (one per cent., if it is desirable to expedite the process, or one-tenth per cent. if it is not necessary to conclude the examination the same day). Then, when the nerve is thoroughly blackened all through, it is to be immersed in water for a few hours; then in ninety per cent. alcohol, and then in a weak solution of gum-arabic, which fills the interstices between the bundles, and finally in strong alcohol, ninety-five per cent., which hardens the gum sufficiently. The sections, cut as thin as possible, should be placed on a slide to remove the excess of alcohol, which may be done with filter paper. A drop of water is then to be added; about the cover put a few drops of carbolized water; remove to a damp place. At the end of twenty-four hours the gum will have dissolved, and then the glycerine may be allowed to enter slowly without displacing the elements (Ranvier).

In examining such cross-sections, the medullated nerves will present various diameters, and the contour of the myelinic sheath will vary in width and outline according as the cut comes through the broadest part of the arrow-marking, or through the thin overlapping parts. (*See* Fig. 1.) If the cut chances to pass close to the annular constriction, no myeline will of course be seen. For these reasons, the cross-sections of such nerves, when stained with osmic acid, are very different.

Modern Conceptions of Myelinic Nerves.—The specimens that have been studied according to the methods given will not have shown any termination in the nerves, or any division, either into trunks of any considerable size or into the fibrils of which they are said to be composed. They do, however, as we have already said, divide both near their origin and near their termination. It is presumed that each fibril of which the axis-cylinder is composed passes directly through from its point of

FIG. 6.

FIG. 7.



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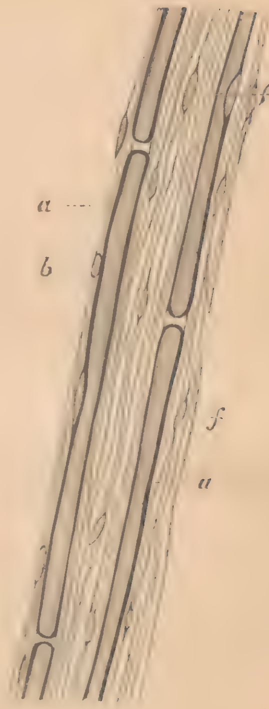

FIG. 6.—FIBRES OF REMAK. A. Pneumogastric of the cat. Hæmatoxylin specimen: *a*, nerve nuclei; *b*, appearances of branching; *c*, connective-tissue sheath. *B*. SAME. Picro-carmine specimen. The branching in this case is more evident. *C*. SAME. Hæmatoxylin specimen. The necklace appearance is shown at *a*.

FIG. 7.—PACINIAN BODY FROM THE MESENTERY OF THE CAT.

FIG. 8.—DIAGRAMMATIC. *a*, Myelinic fibres; *b*, nucleus of Henle's sheath; *f*, nuclei of endothelium, or of connective-tissue corpuscles of sheath.

origin in the nerve-centres, to its final point of distribution, without branching. It is difficult, however, with the instruments in ordinary use, to see any distinct marks of fibrillation in cross-sections of the axis-cylinder, and it is in them that we should expect to see them best. Probably the ideas of Ranvier are the most precise of any of the recent writers. According to him, each section of nerve between the annular constrictions represents an ultimate morphological element. It is in fact a tubular cell, whose proper external portion (the membrane of the cell, according to common phraseology) is the sheath of Schwann, while the myeline or medulla fills the interior, just as in adipose tissue a globule of oil fills out and distends an ordinary connective-tissue corpuscle. Each of these bodies, which he calls an interannular segment, begins and ends at the constriction. It contains a single ovoid flattened nucleus, which fills a niche in the myeline, and is surrounded by a broad, thin expansion of protoplasm (the body of the corpuscle). The axis-cylinder has nothing to do with this body that we have described, except that it pierces it. Instead of stopping short at each constriction, it goes on indefinitely. As we have already seen, the annular constriction and the biconical disk are not always at the same point, which argues strongly for Ranvier's views. At the same time Engelmann insists that there is a break in the axis-cylinder at the annular constriction. The myelinic sheath probably protects the delicate fibre from external injury. Whether it also insulates it, is problematical. In the fœtus all nerves are devoid of myeline.

Fibres of Remak.—These are called by some the amyelinic or non-medullated fibres, by others the pale, gray, or gela tinous fibres. The term Remak's fibres has come into use recently as the distinctive name for certain nerve-fibres abounding in the sympathetic, as distinguished from others which also contain no myeline, and are found in the cranial portions of the optic, auditory, and olfactory nerves. Each fibre is marked with oval nuclei at pretty short intervals, and has an indistinct longitudinal striation, probably the evidence of fibrils such as are believed to exist in the axis cylinder. The nuclei are imbedded in a homogeneous sheath. There being no breaks in

the continuity of the fibre, there can be no sheath of Schwann in the sense that has been described. In diameter they vary between $\frac{1}{250}$ and $\frac{1}{120}$ millimetre. In 1838 Remak first called attention to them, but his views were received with disfavor. More recently, Max Schultze, Frey, Leydig, and Henle have joined in representing them as long, cylindrical, continuous, slightly striated, and dotted with nuclei.

The fibres of Remak are found in great abundance in all the nerves of the organic system, but they also exist in all the mixed nerves, varying with the kind of nerve and the animal. They do not exist in special nerves. The pneumogastric of the cat is well adapted for the study of them, as the myelinic fibres are present in considerable quantity, and make the mechanical separation of the bundle easy. Associated with them are often seen fibres which are shown in Fig. 6, *c*. They are delicate, run a wavy course, and sometimes exhibit curious varicosities (*a*), (necklace appearance). The nuclei are placed at about the same distances apart as in the other form of fibre already mentioned.

Preparation in Osmic Acid and Picro-Carmine.—Remove from a cat that has just been killed the pneumogastric in the following way: Having exposed the nerve, slip under it *in situ* a long narrow strip of cork, to which pin down the nerve with some adjacent tissue, all of which may be removed at once and placed in a solution of osmic-acid (1–1000) for twenty-four hours; the nerve may then be separated from its attachments and placed in the picro-carmine solution for still another twenty-four hours. The excess of the coloring agent may be removed by dipping for a few seconds in acetic-acid solution (one fifth per cent.), and then the nerve may be placed in alcohol, afterward in water, and then mounted in glycerine It will be seen that the nerve fibres are stained a reddish-yellow, while the nuclei are brick-red. The picric-acid yellow is apt, however, to diffuse. Careful separation of the fibres may show that they branch, as shown in Fig. 6, *A*, *B*; and yet this characteristic, which Ranvier insists upon, is by no means easy to see in most of the fibres, in fact it requires much careful work before it is apparent. The myelinic nerves will be distinguished by their greater average size, their dusky, granular

medulla, broken at points, and by the axis-cylinder, which, if it does not project, may be seen winding spirally along beneath its medullary coat. In them, too, as a rule each interannular segment contains but one nucleus.

Preparation of Remak's Fibres in Hæmatoxylin.—One of the most rapid and successful methods is by the use of hæmatoxylin. The pneumogastric nerve of a cat is removed and immediately placed in the hæmatoxylin solution,[1] then, after thorough staining, which may only take a few minutes, in dilute acetic acid (one-half per cent.) and then mounted in glycerine. In this way the nuclei will be stained a beautiful purple, while the fibres will be unaffected. The number of nuclei and absence of medulla will serve to distinguish the fibres of Remak from the medullated. It is difficult by any method of preparation to see that there are any precise limits to the longitudinal lines in the fibres, i. e., that the striation is due to little, short, narrow rods, lying side by side (Ranvier). The nitrate of silver demonstrates no transverse markings and no constrictions or crosses. There is but little likelihood in these specimens to mistake the fibres for connective-tissue bundles. In the first place, the nuclei, and what cell-bodies happen to be about them, of the one, are small, flattened, ovoid bodies occurring at pretty regular intervals, while the connective-tissue corpuscles are usually larger, longer, and, though they may appear oat-shaped when the side is turned to the observer, are broad plates with irregular edges when seen flat-

[1] In 1876 I called attention to the great value of hæmatoxylin in studying connective substances. *On the Structure and Development of Connective Substances*, NEW YORK MEDICAL JOURNAL, July, 1876, and *Monthly Microscopical Journal*, Oct. 1, 1876. The formula then given was: Hæmatoxylini (pulv.) gr. lii, aluminis ℥ j, aquæ ℥ viij. Mix and strain. This solution answered well for showing the neuroglia after an immersion of twenty-four hours. The formula was much the same as had been recommended by Frey (*The Microscope*, 1872, etc., p. 158). I have, however, been in the habit of using it in a much more dilute form, by adding four times the amount of distilled water. This fluid should not be used at once, but be exposed to the sunlight for at least two weeks. It then is to be filtered, and is always to be filtered before using. An alcoholic preparation bearing my name, and put up by a leading pharmacist of the city, I have never used, and consequently have never recommended.

wise. In the second place, the fibres run their course in long, narrow bundles, as no connective tissue does.

Ganglionic Bodies.—Of these there are three kinds: 1. Those that are connected with the spinal and some cerebral nerves. 2. Those found in the gray substance of the brain and spinal cord. 3. Those in the ganglia of the sympathetic system. These bodies are of such large size that they may often be seen with the naked eye. In the human species they are usually in close connection with the origin of the nerves, though they also may be interspersed at points through the course of the fibres or may be present near their points of distribution (ganglia of Auerbach). Their immediate connection with the nerve fibre is made in the following ways: 1. A large process, which does not at first appear to branch, passes off, and is continuous with the axis-cylinder. 2. Fine branches are given off from one or more corpuscles, and, uniting, contrive to form a nerve fibre (either a fibre of Remak or a myelinic fibre). 3. These branches after combination may pass through a ganglionic corpuscle, which then is called bipolar (Gerlach, Waldeyer). In the sympathetic system we have the unbranched process and the superficial or spiral fibre, which corresponds to the branched fibres of the ganglionic bodies of the brain and spinal nerves.

Ganglia of the Cranial and Spinal Nerves.—These organs, which appear to the naked eye as nodular enlargements of the nerves with which they are connected, consist of groups of peculiar large corpuscles which are interspersed among the nerve fibres. In shape they are usually large and ovoid, or pear-shaped. About and between them are bands of connective tissue studded with nuclei forming for each separate body a kind of capsule; the vascular supply to them is liberal. The contents of these bodies are soft, elastic, and beset with granules. They have a large, globular or ovoid nucleus or nucleolus, and may appear to have no process, or to be unipolar or bipolar, as in the lower animals.[1]

Examination of the Gasserian Ganglion in the Frog.—

[1] According to Key and Retzius, they are probably all unipolar. *Stud. in der Anat. d. Nerven-Syst.*, 2 Hälfte, V. and H.'s *Jahresb.*, 1878.

Take a frog that has just been killed, or, better still, one that has been some time in Mueller's fluid ; trace the fifth nerve into the skull. On it will be seen, just within the bone, a yellow enlargement. This is to be removed with forceps and teased with needles. The ganglionic bodies usually appear to have no processes (apolar), but they probably have one or more, and the apparent absence of them is because they have been torn off in teasing.

Examination of the Ganglia of the Spinal Cord.—Take the cord of a bullock and prepare it while fresh, or after it has been a greater or less time in Mueller's fluid, or a weak solution of the bichromate of potash (gr. xv–℥ i). Having cut it into transverse segments, the gray substance may be easily seen. Snip out with fine curved scissors small pieces from the anterior horns in the lumbar regions where the corpuscles are very numerous ; if the specimen be fresh, immerse in osmic acid (1-1000) for twenty-four hours. Then by careful brushing in water with the camel's-hair brush, or by teasing, or agitation in a test tube with a little distilled water, some of the ganglionic corpuscles will be successfully removed. They will be seen to vary much in size, and be multipolar, i. e., they will exhibit a very large number of branches (Deiters's protoplasmic processes) which divide and subdivide, and, it is said, form a network which unites with a similar one proceeding from the ganglionic bodies of the posterior roots.

There is, in addition, a single straight process (naked axis-cylinder), which, proceeding outward, soon receives a medullary sheath. The nucleus is very large and circular, and displays usually a nucleolus. The contents of the body of the corpuscles are more or less granular, and a mass of pigment in granules is usually seen piled up in some one portion. The corpuscles thus separated may be preserved in glycerine and water, or, after staining in borax carmine, in dammar varnish or Canada balsam. In the posterior horns the corpuscles are similar in character but smaller. Gerlach claims that the ganglionic bodies of the anterior horns are connected together through networks formed of the branching processes given off from each. Carrière, working under Prof. Kollman, of Mu-

nich, has examined the spinal cord of the calf in the fresh condition, and has satisfied himself that the ganglionic corpuscles are connected together by their fine processes, being thus in agreement with Stilling, Wagner, Remak, and many others.—*Arch. f. mikroskop. Anat.*, xiv., 2., 1877.

Ganglionic Bodies in the Human Brain.—Thin sections made through the cortex of the human brain show that there are conical ganglionic corpuscles of medium size, whose base is directed toward the white substance, and apex toward the superficies. From either end processes are given off, from the broad end several and from the apex a single one; both subsequently branch. In the upper strata the corpuscles are smallest. Disseminated throughout this substance are two other forms of corpuscles, one star-shaped (spider cells),[1] and the other the lymphoid corpuscles that belong to all tissues of the body. Possibly the spider cells which have a variable number of processes are the cells of the neuroglia. Brush cells[2] have also been described. Perhaps they should also be regarded as a variety of the spider cells.

Ganglionic Bodies of the Sympathetic System.—They occur either in groups, interspersed among the nerve-fibres, or are in lines, or single, or form enlargements in the nerve-plexuses, as in the digestive tract. Preparations of the cœliac ganglion of the frog may be made according to the methods that have already been described. The aorta and bulbus arteriosus of the frog are recommended by Klein. The gold method is the best in this case. It was in these corpuscles of the green tree-frog that Beale noticed a spiral fibre. It was a delicate one, winding round the axis cylinder, finally going off in an opposite direction. He also thought, from an examination of the ganglia in the mammalia, that the same fibre existed in them. Subsequently Julius Arnold corroborated his views, and even described a network of fibres which was connected with the nucleolus, and extended through the corpuscle, finally at its exit forming the spiral fibre. Recent observers, however, have failed to confirm Arnold's opinion,

[1] Described by Jastrowitz.

[2] *Arch. f. mikrosk. Anat.*, 1874, LXI., p. 93.

and even the existence of a spiral fibre is held to be in doubt.[1] These corpuscles, which are either globular or oblong, may appear to be apolar, unipolar, bipolar (when two processes are given off the opposite directions), or multipolar (when two are given off in the same direction, or several are given off in various directions).

Meissner's Plexus.—This network, named after its discoverer, is situated in the submucous tissue, and consists of nerve-bundles of medium size, which have nodular enlargements, studded with nuclei at certain points. An excellent way of securing them is the following: Take a piece of cat's intestine, three or four inches in length; cleanse it thoroughly by passing through it a stream of water; then ligate one extremity. Fill an ordinary two-ounce syringe with a solution of the chloride of gold (½°). Slip the nozzle into the other end of the intestine, and, tying it in, inject with such force as to distend the gut to its utmost extent without bursting. Then pass another ligature round the gut beyond the nozzle, and draw it tight. Remove the syringe, and place the specimen in an open vessel containing the same solution, but allowing fully one-half of it to be uncovered by the liquid. After twenty-four hours the part thus exposed will have taken a mauve or violet color. Then remove from the liquid, and open with scissors, let it partly dry, and, seizing the mucous membrane with the forceps, tear it off in pieces. The submucous tissue will then be exposed, and small bits are to be torn out in a similar way. They may be mounted in glycerine or dammar varnish. The nerve-trunks can be readily seen; they will contain, on an average, perhaps, from two to three fibres, and form a large-meshed plexus. The ganglionic enlargement may be found where three or four bundles meet, or in the course of a single bundle. The diameter of the enlargement is three to five times the size of the bundle.

Auerbach's Plexus, called after its discoverer, is seen by taking the same specimen, and tearing out thin laminae from the muscle, at the junction of their longitudinal and trans-

[1] Key and Retzius did not find the spiral fibre in the human species, but in the frog occasionally. *Op. cit.* Many other excellent observers agree with them.

verse coats. The ganglionic bodies are nodular, and contain numerous nuclei. It is said that they may be isolated by immersion of the muscular tissue eight to ten days in a ten per cent. solution of common salt. Guinea-pigs furnish the best specimens.[1] There ~~are~~ both a coarse and fine network.

Termination of Nerves.—There are several ways that are recognized: 1. By terminal networks; 2. By end-bulbs; 3. By tactile corpuscles; 4. By Pacinian bodies; 5. By motorial plates. When nerves terminate by networks, the meshes may be formed from the medullated fibres, or those of Remak, and may consist of one or more fine fibrils. They have been found in the skin, and are to be seen in the submucous tissue of the intestines, in the cornea, and elsewhere. Termination by bulbs has been closely investigated by Krause. The bulbs are described as having a diameter of $\frac{1}{20}$ millimetre, are ovoid-shaped in man, with a thin capsule of connective tissue. One or more fibres appear to enter the bulb, and, penetrating some distance, end in a knob. They have been found in the conjunctiva, in the mucous membrane of the floor of the mouth, lips, soft palate, and tongue, and in the glans penis and clitoris. In the cavity of the mouth they are placed in the papillae. The bodies Krause has observed in the clitoris are somewhat peculiar; they are variously shaped, and have a mulberry-like surface.

These corpuscles, about which there has been so much discussion and which some excellent observers (Waldeyer, Arnold) had failed to see, have been investigated recently by Longworth,[2] of Cincinnati, and their existence he regards as a matter of no doubt. He took the human eye, freshly removed with the conjunctiva, and made the examination immediately. Attaching the conjunctiva with threads, so that it preserved its ~~its~~ natural tension, he immersed it in a one-third per cent. solution of osmic acid, or exposed it to the vapor of the same solution. After twelve to twenty-four hours the membrane was deeply stained, and the epithelium could usually be removed with a brush or the finger-nail. Next a thin piece of cornea was

[1] Frey, "Das Mikroskop." Leipzig, 1877.

[2] *Archiv für mikroskopische Anatomie*, Bd. ii., Hft. 4, 1875.

removed and examined in water, or in one to two per cent. acetic-acid solution. It was then mounted in glycerine. This method is preferred to the gold chloride. In some conjunctivæ they are almost entirely absent; in others, or in certain portions, quite numerous. The entire interior is filled with nucleated corpuscles. Waldeyer, in commenting on the work of Dr. Longworth, agrees to it fully and retracts his former opinions. He places these bodies intermediate between the tactile and Pacinian bodies.

The tactile corpuscles of the skin (called also Meissner's or Wagner's corpuscles) are to be seen in the papillæ, and especially well in the tips of the fingers, and in the internal genitals. They have a length of about $\frac{1}{10}$ millimetre. Specimens hardened and preserved in the ordinary way show them well. They are oblong, rounded, and marked by transverse wavy lines. A nerve fibre may be seen running into their centre.

The Pacinian bodies, discovered by Vater, in 1741, but first carefully described by Pacini, of Pisa, are oval or pear-shaped bodies, attached to the nerves like berries to a stem. They are found in the subcutaneous tissues of the finger (Koelliker,) in the labia majora, prostate, corpora cavernosa, and in many other places. They are seen to the best advantage, however, in the mesentery of the cat, where they are so large as to be easily visible to the naked eye.

Cut out a small piece of the mesentery, place it in a weak solution of osmic acid (1–100), and after a few minutes, when it has become brown, separate the capsule carefully with needles. Mounting at once in glycerine, the whole interior of the Pacinian will be superbly shown, constituting one of the most beautiful specimens in histology. The medullated nerve may be seen winding at one end (Fig. 7), covered with a dense coating of connective tissue, and accompanied by a small artery. After penetrating a variable distance, it leaves its medulla and is continuous with a straight fibrillated band that is called the core. It terminates apparently in one or more granular expansions. In two cases I saw the nerve apparently passing through the body, giving off its medulla on entering it, and assuming it again on leaving.

This has been observed by Klein, Pappenheim, and others. Round about the core, forming a series of pretty regularly oval markings, are concentric tunics. Toward the periphery they are at a pretty even distance apart. Between them, applied closely to the tunics,[1] are small ovoid nuclei. The spaces between the lamellæ are probably filled with a clear fluid. In my experience these bodies are not successfully preserved in glycerine, even after hardening in osmic acid. The chloride of gold is recommended.

Nerve terminations in muscle are quite easily seen. It is only necessary to take a bit of muscle from the thigh of a frog just dead, and immerse it in dilute acetic acid, and then in glycerine. When the tissue is thoroughly transparent, as it will be in a few minutes (ten or fifteen), there will be little difficulty in finding first a medullated fibre, and then in tracing it into a muscle fibre. Reaching the sarcolemma it penetrates it at a prominence (Doyère's eminence). From this point it divides into fibrils which form delicate networks, and some one, or possibly two fibres will be seen to enter an irregular body placed in the centre of the fibre. This body is highly nucleated and may without much difficulty be distinguished from the muscle nucleus, which, however, usually lies on the bundle and not in it. This body is called the motorial plate, or terminal body. It is not certain, however, that the ultimate fibrils actually end there, for in some instances one is in connection with one side, and one with the other. Varicosities are described in the primitive fibrils when osmic acid or chloride of gold is used.

Gscheidlen,[2] of Breslau, one of the most recent writers on this subject, has traced (in the leech) the ultimate fibrils to the cement substance between the contractile muscle corpuscles (unstriped muscular tissue). He never saw them end in plates or in networks. Ganglion cells are closely attached to the fibres near their termination, and they may be unipolar, bipolar, or even multipolar, the former being the most numerous.

[1] According to Shaefer the nuclei belong to epithelioid corpuscles which cover the tunic on both sides. "Practical Histology," p. 134. *Quarter. Microscop. Journ.*, 1875.

[2] *Archiv für Mikroskopische Anatomie,* xiv., 3, 1877.

Termination of nerves in epithelial bodies has been described by a good many observers. The demonstration of such ending, however, is extremely difficult.[1] The ultimate fibrils are liable to be confounded with elastic tissue, possibly with connective-tissue fibres. To be quite sure of their character they should be traced into connection with nerve trunks on the one hand, or ganglionic bodies on the other.

Connective Tissue of Nerves.—In our description we have adhered to the idea that the sheath of Schwann is the one that immediately incloses the medulla, without intervening substance. Ranvier has called the first sheath, exterior to Schwann's, "the sheath of Henle." (Fig. 1, *e.*)

The term *perineurium* is often applied to the sheaths of the funiculus or bundle. The connective tissue separating the funiculi in a large trunk has been called *endoneurium*, while *epineurium* is the great sheath of the whole trunk. Each bundle or funiculus, the smallest element that we see in making a gross dissection of a nerve, is covered with one or more layers of endothelium, forming a special sheath. These funiculi do not run parallel without anastomosing, but two, joining, form a third, which again divides.

There is a practical difficulty in the way of giving precise limits to these sheaths, in the fact that they are apt to be continuous one with the other, while some one or more of them may be absent, depending upon the size or quality of the nerve. Such distinctions are therefore generally useless; and, in fact, our notions of these matters will alter as histological knowledge increases, and especially as we come to understand the minute anatomy of the lymphatics, which doubtless course in between the fibres.

[1] *See* Cohnheim, Virchow's *Archiv*, Bd. 38, p. 343; and Krause, *Archiv für Mikroskopische Anatomie*, Bd. xii., Hft. 4, 1876.